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THE STRUCTURAL POTENTIAL OF BAMBOO: A STUDY OF THE COMPRESSIVE AND TENSILE STRENGTH OF *BAMBUSA TULDA* SPECIES

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ABSTRACT

The increasing consumption of steel and timber as major structural construction materials has led to adverse environmental consequences world over. Processing of steel products is known to be associated with emission of certain gases that degrade the environment and continued use of steel will certainly lead to depletion of the existing raw materials for the manufacture of steel. Harvesting of trees for the manufacture of timber products applied in construction has contributed to wanton destruction of our forests at unprecedented rate. The foregoing suggests investigations of alternative structural construction materials that are environmentally sustainable. This study therefore focused on making an enquiry on the compressive and tensile strength of Bambusa tulda bamboo which is a renewable fast-growing wood plant. Specimens for compressive and tensile strength tests were prepared and subjected to laboratory tests through use of INSTON 300 DX Universal hydraulic Testing Machine. The findings of the study showed the average compressive strength achieved was 40.0 N/mm^2 which was reasonable compared with those from the conventional structural construction materials and therefore appropriate for use as compressive structural materials. On the other hand, the average tensile strength obtained from the experiment was 58.9 N/mm^2 which is marginally low implying bamboo cannot be applied as a tensile material in structures subjected to heavy loading but minor structural elements such as lintels and worktops as well as low rise structures.

KEYWORDS: *Bambusa Tulda Bamboo, Compressive Strength, Structural, Tensile Strength*

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INTRODUCTION

With the big four agenda crafted by the Kenyan Government coupled with the high demand of sustainable construction materials for the fast-growing Kenyan construction industry, finding a solution to this problem will make it possible to facilitate affordable construction materials and technology. Bamboo as an alternative construction material is however a cheaper sustainable fast-growing plant compared to timber and steel; and could be applied as a replacement of timber or steel (*Republic of Kenya, 2019; Swapnil and Smita, 2017; Chinese Bamboo Research Council, 2009; Kibwage, 2010 and Bethany, 2010*).

The study therefore evaluated the structural potential of bamboo as a sustainable construction material. The research paper consists of the abstract, theory on bamboo as a sustainable construction material, experimental methodological approach that was adopted as well as results and discussion section. It finally concludes on the key findings of the study. Listing of the references and appendices appear at the end of the paper.

THEORY ON BAMBOO AS A SUTAINABLE CONSTRUCTION MATERIAL

The unique properties of bamboo, coupled with its cost effectiveness has prompted a number of research initiates on how it could be applied as a reinforcement material in construction. *Ghavami* (*2005*) believes that bamboo could satisfactorily substitute steel as a reinforcement material and consequently frantic efforts should be made by researchers to establish its potential strength in structural design. This is coupled with the fact there is need to ensure the sustainability of the future generation through exploitation of sustainable materials in construction for which bamboo is among them. Indeed *Vyas* (*2020*)*, Hebel* (*2015*)*, Kibwage* (*2008*) *and; Balaguru and Shah* (*1985*) emphasize the potential of bamboo as renewable resource that in fact could be utilized as a reinforcement material in the construction of rural structures. Kenya should not be left behind in this matter. *IRIN* (*2010*) suggests that bamboo has the potential of providing affordable housing for 60% of Kenyans who live in slums and other squatter settlements under squalid conditions.

This argument has opened doors for sustained research in this area to better understand whether bamboo could be a cheaper environmentally sustainable replacement of steel in construction. *Gichohi* (*2014*)*, Bethany* (*2010*) *and Kibwage* (*2010*) agree with this thought by expressing that a house constructed with bamboo could last for approximately 50 years while the energy consumed to produce bamboo about is 1/2 for wood, 1/8 that for concrete and 1/5 that for steel. According to *Swapnil and Smita* (*2017*) bamboo reinforcement is three times cheaper than steel and in addition it is a versatile material with a high strength-to-weight making it appropriate for applicable in affordable housing and in particular in structures of no more than one suspended floor while *Karthik, Rao and Awoyera* (*2017*)*, Kibwage* (*2010*)*, Chinese Bamboo Research Council* (*2009*) *and Steinfied* (*2001*) indicate that bamboo has strong mechanics, good adaptability and easily processed traits that gives it a wide range of architectural and industrial applications. Some studies have explored ways of using bamboo reinforced concrete beams which are simple and structurally effective as well as cost effective. *Abdullah* (*1983*) in his study concludes that the strength of bamboo and its relative cost effectiveness could be exploited to facilitate low-cost housing initiatives in the third world nations riddled with housing dilemma for the poor (*Abdullah, 1983*). A study by *Adom and Afrifa* (*2011*), in an effort to establish a cost-effective solution for reinforced beam construction for application in affordable construction in Rural Ghana revealed that the tensile strength of bamboo reaches up to 370 N/mm^{2}. *Khare* (*2005*) reinforces this argument by expressing that bamboo reinforcement enhances the load carrying capacity by about 250% as compared to the initial crack load in un-reinforced concrete beam. According to *Glen* (*1950*) load capacity of bamboo reinforced concrete beam increases with increasing percentages of bamboo reinforcement up to an optimum value. On the other hand, axial tensile young modulus varies from 5 – 25 Gpa and axial tensile strength varies from about 100 – 800 Mpa for specimens taken from inner and outer culm respectively (*Shao et al, 2010*). The implication of these findings is that bamboo could therefore be applied as an alternative reinforcement material in affordable construction as a replacement of steel which is comparatively expensive. The physical and mechanical properties that makes it favourable in a wide range of applications however vary with respect to diameter, length, age, type/species, position along culm and moisture content (*Lo, Cui and Leung, 2004*). The foregoing arguments indicate that the use of bamboo to provide tension in structural design is therefore not in doubt.

In addition to tensile strength, some studies have also been directed to bending and compressive stresses. *Espiloy* (*1987*) established an increase in compressive and bending strengths towards the top portion of the culm as fibrovascular bundle frequency and dimension of the fibre vessel increases. This finding is explained by significant increase in relative density and fibrovascular density. Compared to conventional species common in North America, along axial direction,

Moso bamboo is substantially stiff as well as stronger in both flexural and compressive strengths (*Dixon and Gibson, 2014*). Further findings in this study revealed that axial properties of Moso bamboo increase linearly with density whereas the transverse compressive strength indicated minor variation. Again, bamboo as a compression member has good elasticity in tensegrity structures (*Jagadesh, 2014*). According to *Lee, Bai and Peralta* (*1994*)*; Lo, Cui and Leung* (*2004*)*; and Chung and Yu* (*2002*) the compressive and flexural properties of bamboo along the grain increases with the height of the culm and decreasing moisture content. Moisture content and height of the bamboo culm therefore influences its strength. A comparison of bigger tubes to slimmer ones shows slimmer ones have a higher compressive strength (*Jagadesh, 2014*). It can there be concluded that past research has consequently revealed the potential application of bamboo to with respect to compressive forces in structural design.

Despite a number of previous researches confirming the applicability of bamboo in tension and compression in construction, it has some limitation. One of the key constraints is associated with its structural limitation for application in wide spans and high-rise constructions. Previous research indicates stiffness and weight requirements as possible limiting factors in the structural design and use of bamboo especially the Moso species (*Dixon and Gibson, 2014*). In addition, its low breaking force and elasticity modulus makes it not appropriate for use as main structural members but could be applied for other structural works that are not subjected to heavy loading and in particular low-rise structures (*Ogunbiyi et al, 2015; South East Asian Community Access Programme, 2008; Adewuyi, Otukoya and Olaniyi, 2015 and; Ketter, Nyomboi and Abuodha, 2014*). The other key drawbacks in applying bamboo as a reinforcement material in concrete components include bonding constraints with concrete and high-water absorption capability (*Mumero, 2020; South East Asian Community Access Programme, 2008; Constructor, 2020 and Steinfied, 2001*). *Constructor* (*2020*)*, Limbe* (*2013*)*, Vyas* (*2020*)*, Chu* (*2014*)*, Gibson* (*2014*) *and Glen* (*1950*) argue that bamboo has high shrinkage requiring preservation and also less durable if not treated for insect and fungi attack. Researchers have however established better ways of preserving bamboo to limit its shrinkage. *Sonti* (*1990*) invented an ASCU method of preserving bamboo that is effective which neither reduces structural strength in compression/bending nor facilitating loss of preservative between the septa. Lastly, the other constraint is the limitation of bamboo as a tensegrity structure focusing on how to transfer the structural forces in wires into whole section of bamboo but this could be addressed through pre-tensioning and winding process that involves applying additional clip at the wire connections and use of plates with mechanism to attach rigidity with the bamboo wall (*Widyowijatnoko, Aditra and Widuri; 2015*).

By and large the suitability of bamboo as a reinforcement material outweighs its limitation some of which such as high-water absorption, susceptibility to insect/fungal attacks and its limitation as a tensegrity structure can now be addressed, thanks to recent research findings highlighted above. The low structural capacity indeed confines its application to structures where loading requirements are not very heavy such as low-rise buildings and scaffolding.

With the cost of conventional reinforcement materials such steel and timber reaching unprecedented levels coupled with their adverse environmental impacts, it certainly makes sense to specify bamboo as an alternative structural material since it is also environmentally sustainable. From the above solicited literature review there is scanty research undertaken to investigate structural suitability of *Bambusa tulda*, a species that is prevalent in Kenya. This study therefore, focused on an enquiry into the suitability of *Bambusa tulda* bamboo as an alternative sustainable structural construction material.

RESEARCH METHODOLOGY

Bambusa tulda is one of the dominant bamboo specie in Kenya and is prevalent in most parts of Kenya. An investigation of its structural strength could open up avenues for its economical exploitation as a structural material in place of steel whose cost has recently become unbearable. In addition, steel which is a heavily consumed construction material has proved to be environmentally un-sustainable. In addition, timber products have equally become expensive while natural forests have been exploited to the level that has become environmentally un-sustainable. The foregoing justifies the need to research on alternative structural construction materials. The study therefore intended to determine the compressive and tensile strength of *Bambusa tulda* to establish its structural adequacy in construction.

The research design was experimental involving laboratory tests of compressive and tensile strengths of adequately dried *Bambusa tulda* specimens obtained from a private plantation in the suburbs of Kisumu City along Lake Victoria's shores. Accordingly, descriptive statistical analysis was adopted. Mature *Bambusa tulda* was purposively selected by the author to ensure culms free from defects were selected and dried under controlled conditions to a moisture content of approximately 15 %. Scientifically, too much moisture in bamboo undermines its structural strength while too much drying causes the fibres to crack and hence weakens it. The samples were hot dried at 103^{o} c for 24 hours in an oven in line with moisture control procedure adopted by *Awalludin et al* (*2017*). The specimens were both weighed prior and after drying to ensure they had acceptable moisture content

Specimens for compressive tests were selected from top, middle and lower bamboo stem with an average diameter of 43mm and height of 102mm and prepared as shown in Figure 1.

Figure 1: Specimens for Compressive Test.

Five bamboo culms without nodes were considered for testing using INSTRON 300 DX universal hydraulic testing machine as shown in Figure 2.

Figure 2: Specimen Undergoing Compressive Strength Test.

Specimens for tensile strength tests were split from bamboo culm walls in to average size of 10mm width and 3mm thickness. The lengths of the specimens averaged 100mm. The adequately dried specimens were then roughened at the ends to ensure firm grip by the testing machine. The specimens were mounted on INSTRON 300 DX universal hydraulic tester. A tensile load was applied uniformly up to failure. The load at failure was recorded and used to calculate the tensile strength using this formula;

$$F_t = F_{max}/A$$

Where;

F_t = tension strength (N/mm^2)

F_{max} = maximum load (N)

A = Cross-sectional area (mm^2)

Figure 3 shows the prepared specimens for tensile strength testing.

Figure 3: Specimens for Tensile Strength Test.

Five specimens were considered for tensile strength test as shown in Figure 4.

Figure 4: Specimen Undergoing Tensile Strength Test.

RESULTS AND DISCUSSIONS

This section lays out results based on compressive and tensile strength readings obtained from laboratory tests whereby the specimens were mounted on INSTRON 300 DX universal tester. The results were tabulated and later discussed by comparing with previous related studies obtained from critical review of literature under the subject of study.

Compressive Test Results

Appendix I shows graphs that indicate the relationship between loading and extension when the five specimens were being subjected to compression. The graphs indicate the loading (compression) (N) versus the change in length (mm), as the specimens are subjected to loading. The specimens extended under increased loading up to a certain yield or failure point when it crumbles under compression. The required loading before failure was directly proportional to the size of the sample. The compressive test results obtained from testing the specimens are shown in Table 1 which also captures the specimens' dimensions.

Table 1: Samples' Dimensions and Compressive Test Results

Sample No	Diameter (m)	Area (m^2)	Thickness(m)	Length (m)	Load at Failure (KN)	Extension at Failure	Compressive Strength (N/mm^2)
1	0.042	0.001385	0.009	0.110	37.853	4.2	27.322
2	0.045	0.00159	0.008	0.105	53.628	4.5	38.712
3	0.043	0.001385	0.009	0.105	54.528	3.8	34.288
4	0.042	0.001385	0.009	0.105	59.144	9.0	42.691
5	0.044	0.001452	0.010	0.104	64.271	6.4	44.252

From the results in Table 1, it is noted that the readings obtained from tests carried on specimen 1 on loading at failure and compressive strength varied significantly from those obtained from the other 4 specimens implying these are outliers. The significant variation could be attributed to some structural defects on specimen 1 which might not have been discovered prior to testing or alternatively it could be improper positioning of specimen 1 on the tester machine. By and large, the readings on specimens 2 to 5 show some level of consistency. From the experiment, the loadings at failure and

compressive strengths varied from 53.6 to 64.3 KN and 34.3 to 44.3 N/mm^2 respectively. The average loading at failure for *Bambusa tulda* bamboo species was therefore 57.9 KN. On the other hand, the average compressive strength for *Bambusa tulda* bamboo was 40 N/mm$^{2.}$ In addition, as shown in Appendix I, as the loading increased extension also increased proportionally until failure after which there was no more extension of the various specimens.

The range of compressive strengths of approximately 34.3 to 44.3 N/mm^2 obtained from tests is quite good and is within the range of compressive strengths of various common classes of concrete used in construction as defined in the BS Standards. Further, according to *Awalludin* (*2017*), compressive strength of *Bambusa tulda* is higher than that of soft wood while it is at par with the strength of most hard wood. Since there are no known similar studies conducted on *Bambusa tulda*, comparisons of the findings with previous research just focused on studies concerning other species of bamboo. Most previous research reveals findings that mirror the findings from this study with a few that are divergent. *Bambusa tulda* accordingly has a higher compressive strength than bamboo Jawa (18.2 – 30.6 N/mm^2) but its compressive strength falls within a range of 34.2 – 60.5 N/mm^2 for Bamboo Apus (*Rochim et al, 2020*). Its compressive strength is not far from that of Bambusa vulgaris which ranges from 49.9 to 51.7 N/mm^2 (*Mbuge and Gumbe, 2022*). The findings by *Candelaria and Hernandez* (*2019*) on Bambusa blumeana species indicate higher compressive strengths that range from 63 – 77 N/mm^2 which also do not agree with readings obtained from this study. The variations in compressive strengths may be attributed to species/type, age, length, diameter and moisture content (*Lo et al, 2004*). By and large the findings compare well with related previous research work. The findings therefore, indicate suitability of application of *Bambusa tulda* bamboo as an alternative compressive construction material. *Limbe* (*2013*)*, Steinfied* (*2001*) *and; Swapnil and Smith* (*2017*) however argue that bamboo has other disadvantages such as strong water absorption, low resistance to fire, weak bonding with concrete and susceptibility to attack by insects. With increased research in this area, most of these limitations can now be comfortably addressed (*Sevalia et al, 2013 and Agarwal et al, 2014*). Its faster growth, low cost and high compressive strength coupled with its environmental sustainability enhances its potential as an alternative construction material.

Tensile Test Results

Appendix II shows graphs that indicate the relationship between loading and extension when the five specimens were being subjected to tension. The graphs indicate the loading (tensile) (N) versus the change in length (mm), as the specimens are subjected to loading. The specimens extended under increased loading up to a certain yield or failure point when it snaps under tension. The required loading before failure was directly proportional to the size of the sample. For example, specimen no. 4 with the largest cross-sectional area extended the most and requires the highest tensile loading before failure. The tensile test results obtained from testing the specimens are shown in Table 2 which also captures the specimens' dimensions.

Table 2: Samples' Dimension and Tensile Test Results

Sample No	Length (m)	Width (m)	Thickness (m)	Cross Sectional Area (m²)	Tensile Load at Failure (KN)	Extension at Failure mm	Tensile Strength (N/mm²)
1	0.107	0.01	0.003	0.00003	1.722	7.5mm	57.4
2	0.1	0.01	0.003	0.00003	1.13	4.5mm	37.7
3	0.1	0.01	0.004	0.00004	2.3	8.2mm	57.5
4	0.11	0.01	0.003	0.00003	1.85	6.7mm	61.7
5	0.1	0.009	0.003	0.000027	1.29	5.2mm	47.8

From the results in Table 2, it is noted that the readings obtained from tests carried on specimens 2 and 5 on loading at failure and tensile strength varied significantly from those obtained from the other 3 specimens implying these are outliers. The significant variation could be attributed to some structural defects on specimen 2 and 5 which might not have been discovered prior to testing or alternatively it could be improper grip of the specimens by the tester machine. By and large, the readings on specimens 1, 3 and 4 show some level of consistency. From the experiment, the loadings at failure and tensile strengths varied from 1.72 to 2.3 KN and 57.4 to 61.7 N/mm^2 respectively. The average loading at failure for *Bambusa tulda* bamboo species was therefore 1.96 KN. On the other hand, the average tensile strength for *Bambusa tulda* bamboo was 58.9 N/mm$^{2.}$ In addition, as shown in Appendix II, as the loading increased extension also increased proportionally until failure after which there was no more extension of the various specimens.

The range of tensile strengths of approximately 57.4 to 61.7 N/mm^2 obtained from tests was relatively low compared with those from mild steel. According to *Ogunbiyi et al* (*2015*) the tensile strength of mild steel with similar dimensions ranges from 290 to 509 N/mm^2 while for bamboo it ranges from 31 to 94 N/mm^2. *Mbuge and Gumbe* (*2022*) indicate the tensile of Bambusa vulgaris bamboo ranges from 94 to 118 N/mm^2 implying it is structurally stronger than *Bambusa tulda* which was investigated. Bamboo Apus and Bamboo Jawa are equally stronger and possess tensile strengths that range from 101 to 232 N/mm^2 and 73 to 214 N/mm^2 (*Rochim, Latifa and Supriyadi, 2020*). The findings by *Candelaria and Hernandez* (*2019*) on Bambusa blumeana species equally indicates higher tensile strengths that range from 180 – 600 N/mm^2 which also do not agree with readings obtained from this study. On the other hand, *Lo et al* (*2004*) argue that the tensile of Moso bamboo ranges from 45 to 65 N/mm2 which compares well with the readings obtained from this study. *Omaliko and Ubani* (*2021*) however view that structural strength of bamboo can greatly be influenced by variations in age, density, moisture content and size of specimens in addition to type or species. The specimens tested underwent sharp brittle failure as opposed to steel that undergoes plastic deformation before failure. This finding is supported by *Ogunbiyi et al* (*2015*).

CONCLUSION

The findings from the study show compressive strengths that range from 34.3 to 44.3 N/mm^2. It can therefore be stated that bamboo has adequate compressive strength making it suitable for construction in situations where compressive forces are at play. On the other hand, the tensile strengths of bamboo ranged from 57.4 to 61.7 N/mm^2 indicating that the tensile strength of bamboo is low compared to the conventional reinforcement materials such as steel. Despite this, bamboo can be applied to construction works with minor structural elements such as lintels, worktops, roofing structure and scaffolding. It could also be ideal for various elements of low-rise residential buildings just as the case of low-cost housing construction in the Far East. In Kenya it is noted that while there is a draft legislation in place concerning bamboo farming industry, no code of standards has been developed that could guide the application of bamboo as a structural material. It is therefore, recommended that the relevant institution(s) put(s) in place mechanisms for developing a code for providing standards to guide use of bamboo as a structural element. Finally, this study only focused on investigating the compressive and structural strength of *Bambusa tulda* bamboo, further studies should focus on other mechanical properties such as flexural or bending strength.

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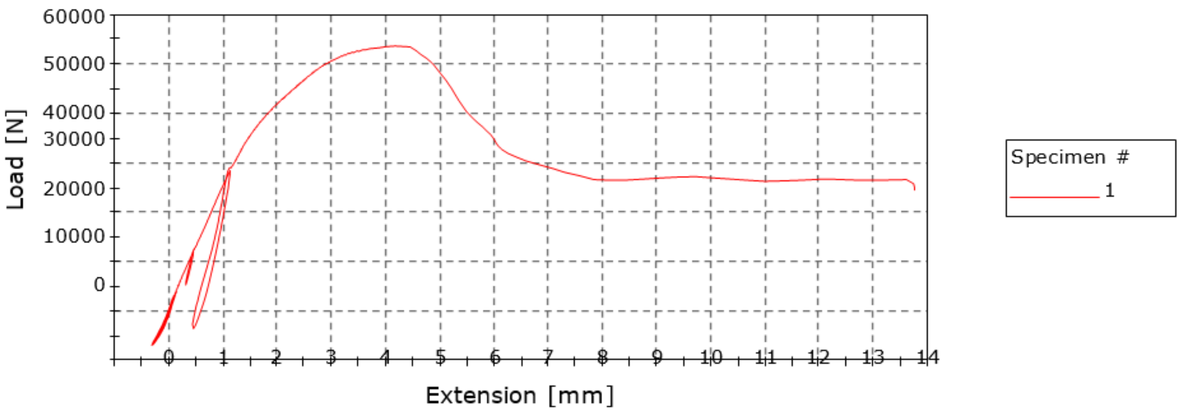
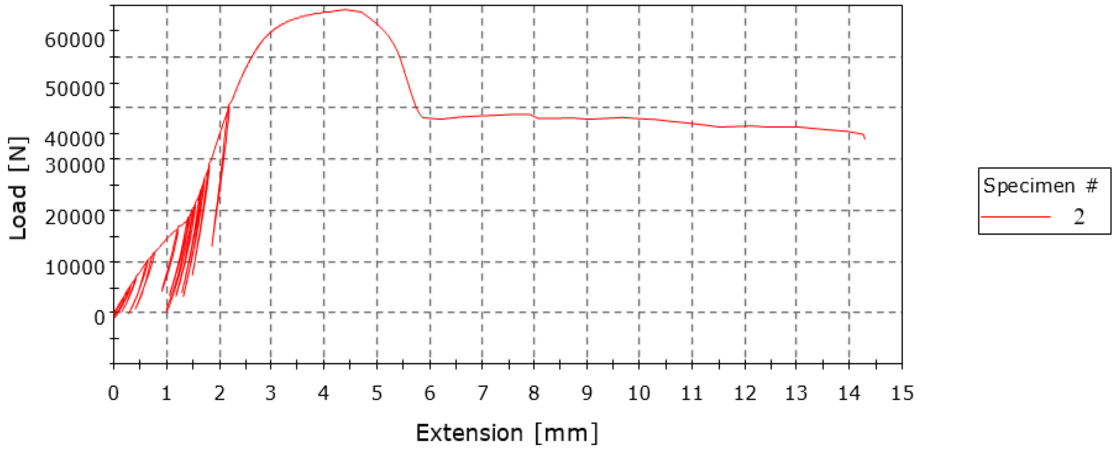
APPENDICES: LOADING VS EXTENSION GRAPHS

APPENDIX I: COMPRESSION TESTS - LOAD VS EXTENSION GRAPHS



Specimen 1.



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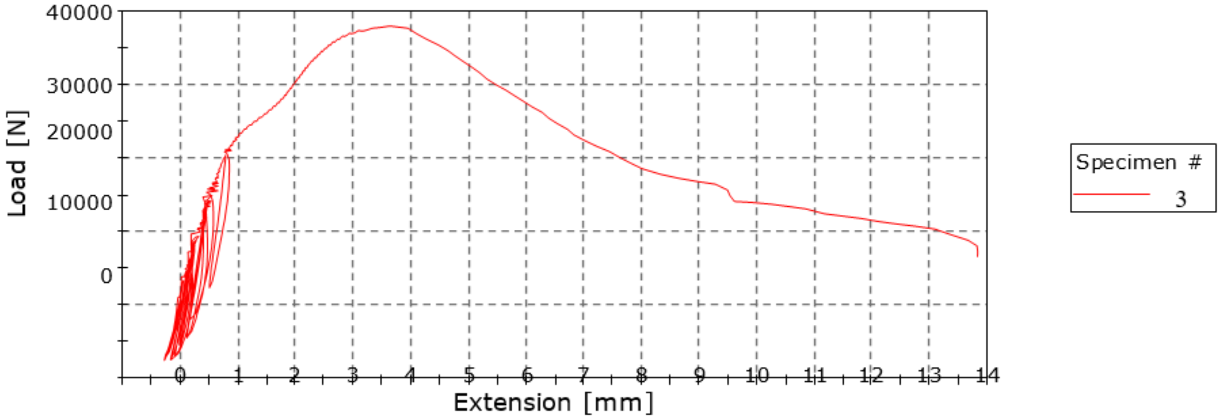

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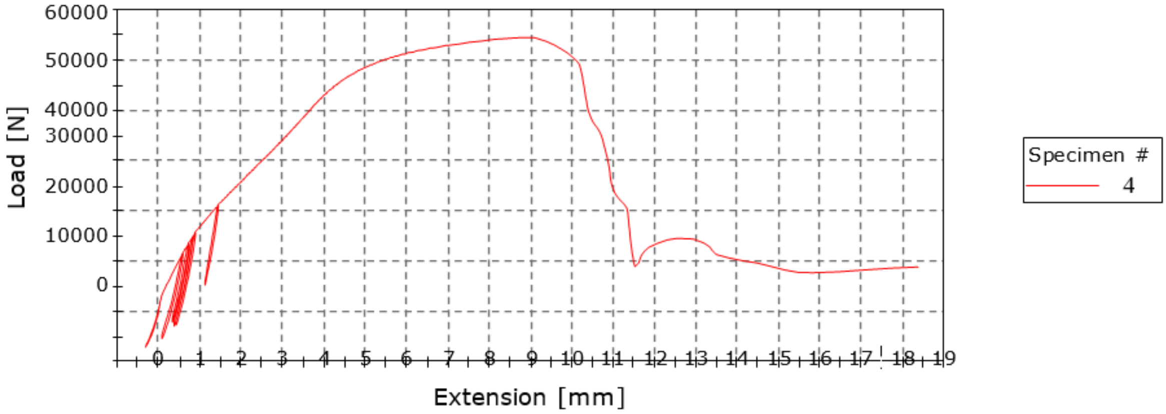
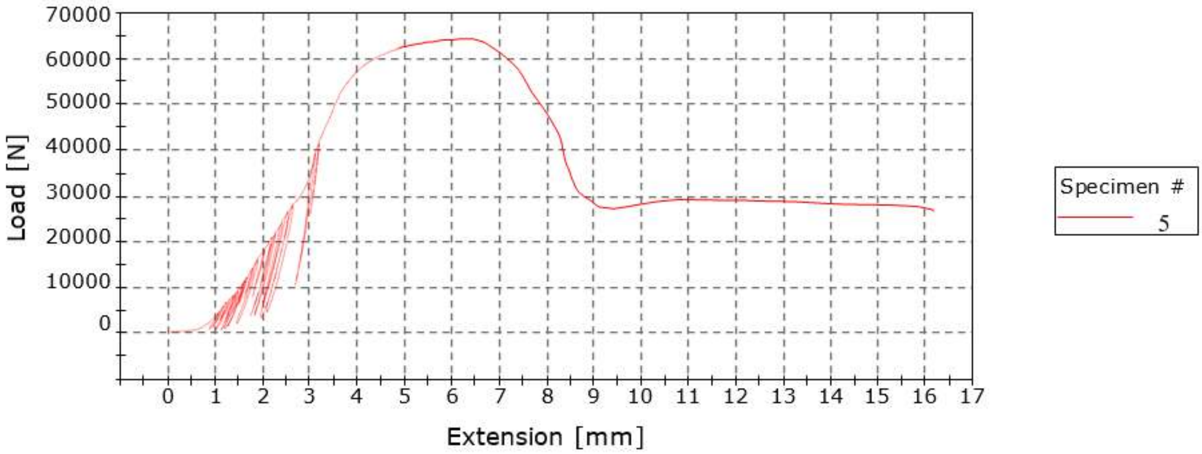
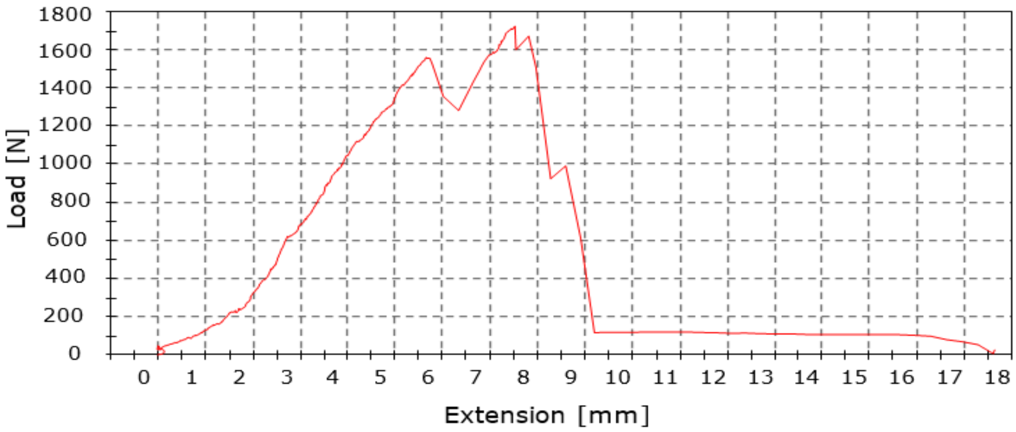


Specimen 4.

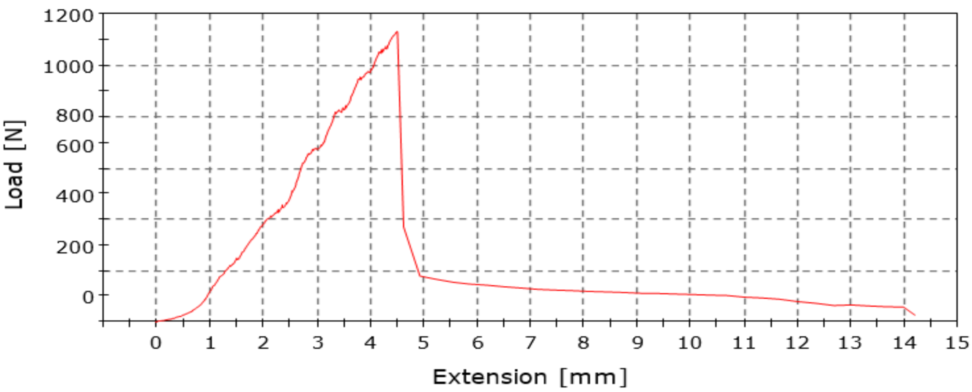


Specimen 5.

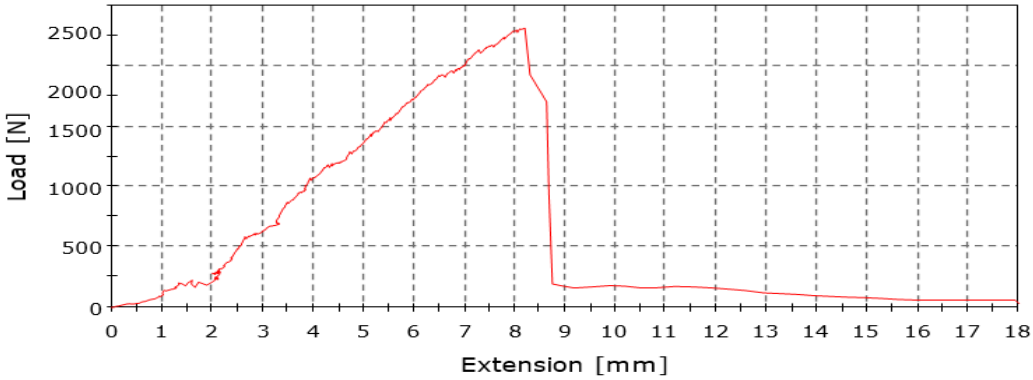
APPENDIX II: TENSILE TESTS - LOAD VS EXTENSION GRAPHS



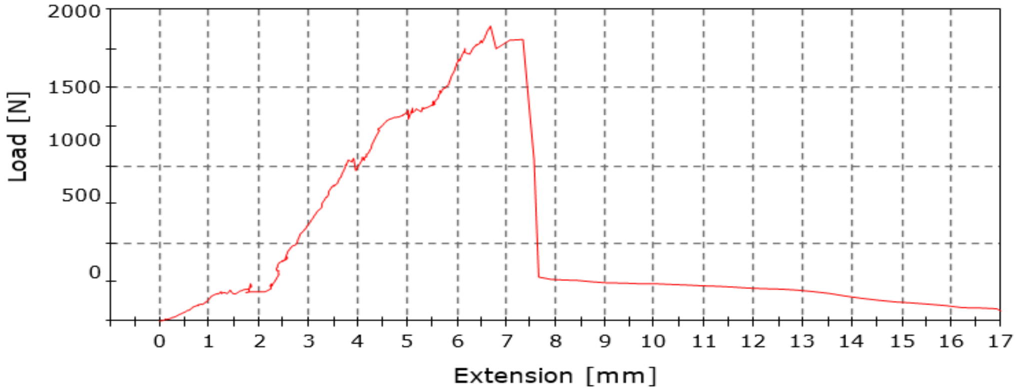
Specimen No 01.



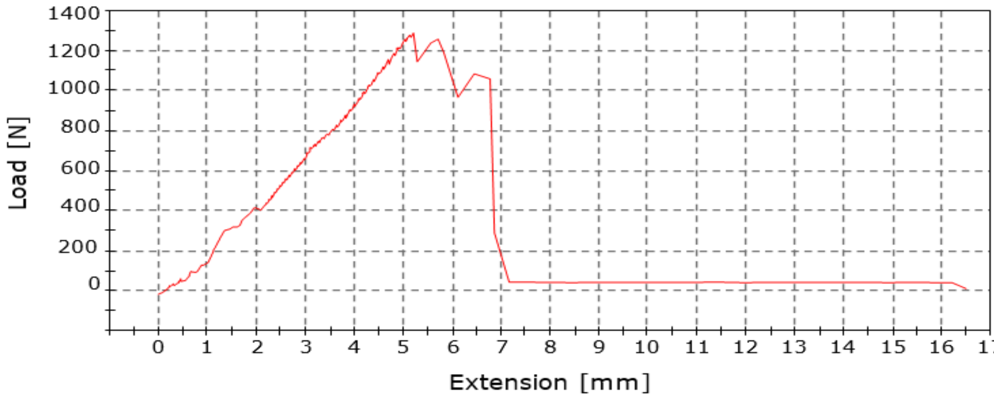
Specimen No 02.



Specimen No 03.



Specimen No 04.



Specimen No 05.